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Data Ecosystems for the Sustainability Transformation

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Executive Summary

In the coming years, we must set a course that will allow as to protect our climate, reduce resource consumption, and preserve biodiversity. A profound ecological system change is on the horizon in all central areas of action of the economy and society, or transformation arenas.

Digitalisation is a prerequisite for the success in this change and will impact these arenas at multiple levels: Digital technologies and applications will make it possible to improve current procedures, processes, and structures (**Improve**) and help us take the first steps towards new business models and frameworks (**Convert**). Despite this, digitalisation itself must be effective enough to facilitate a complete ecological restructuring of our society and lives to achieve more far-reaching economic transformation and value creation (**Transform**).

The ability to obtain, link, and use data is a basic prerequisite for tapping into the potential of digitisation for sustainability transformation. However, data is not a homogeneous raw material. Data only gains value when we know the context in which it was collected and when we can use it for a specific purpose.

The discussion on what structures and prerequisites are necessary for the system-changing use of data has only just begun. This study was conducted to serve as a starting point for this discussion as it describes the **opportunities and prerequisites for a data-based sustainability transformation.** This study focuses on environmental data, data from plants, machines, infrastructure, and IoT products. Our task will be to increase the use this data for systemic solutions (system innovation) within transformation arenas where different stakeholders are working together to initiate infrastructure, value chain, and business model transformation.

Against this background, the **collaborative handling of data** will be a basic prerequisite for the success of this transformation. Therefore, we need new technical, organisational, and institutional prerequisites to create **data ecosystems that support this sustainability transformation.** We will also need an integrated approach to realise these prerequisites (Figure 1):

- All actors, companies, organisations, and public institutions involved in this transformation must acquire the capacity to collect, process, and make data usable. In this regard, many industry actors still have a long way to go, particularly small and medium-sized enterprises and public institutions.
- System innovation needs data ecosystems for collaborative data use. Reliable and trustworthy technical infrastructures, data architectures, and data access and use rules will make it easier for multiple actors to jointly develop digital system innovations without giving up sovereignty over their own data. Interoperability will be the basic prerequisite for collaboration as it will enable data and information to be exchanged between systems and components. This interoperability can be achieved through standards, ontologies, and metadata exchanges.
- Collective action will require common goals and the willingness to commit significant resources, especially financial resources. Our task is to set the guardrails for these commitments through a mission-oriented transformation policy, by aligning system rules to sustainability and creating economic incentives for investments in transformative, data-based system innovations. The use cases currently utilized by initiatives related to the International Data Space (IDS) or Gaia-X must continue to better address the challenges of climate, resource, and environmental protection.
- Our system knowledge of the state of the world and expected developments must constantly evolve. Open data strategies will enable access to data about the environment

and other socially relevant information. These approaches need to be expanded to broadly establish a culture of data sharing.

The technical foundations for building and using data ecosystems are already available or are currently being built. Our next task is to bring together and advance the approaches outlined above. Over the next few years, there will be a promising window of opportunity that must be exploited.

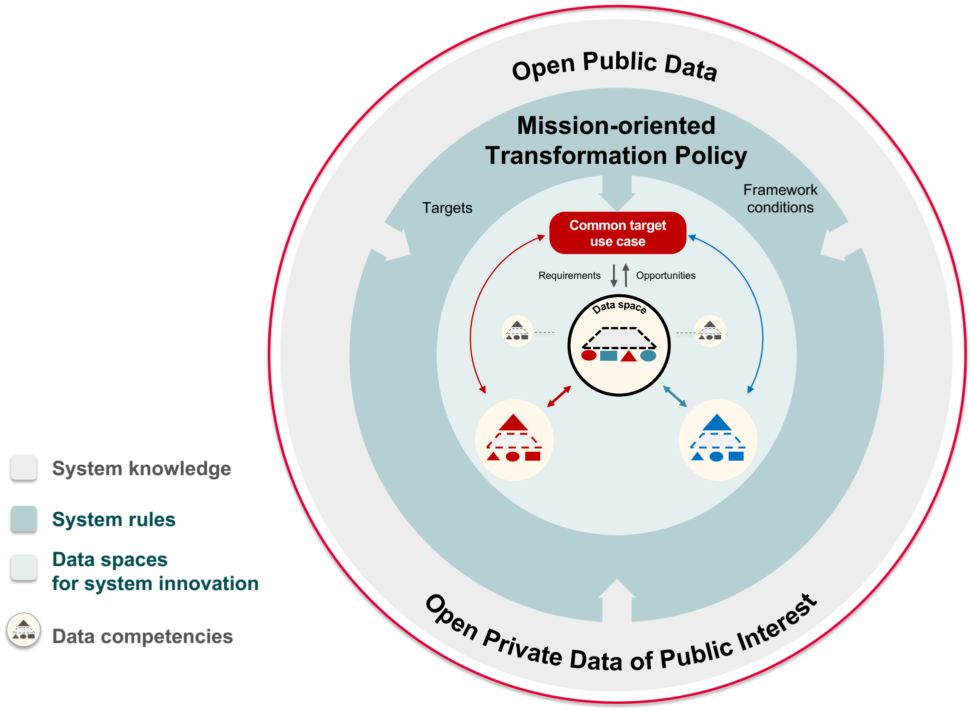

Figure 1: Data ecosystems for sustainability transformation (source: own presentation)

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1 Introduction

In the coming years, society, business, and politics will face the particular challenge of setting the course for climate protection, reducing resource consumption, and preserving biodiversity. This task is already quite urgent. The climate neutrality goals of both Germany and the EU have been moved up to 2045 and 2050, respectively, meaning efforts to reduce greenhouse gas emissions must be accelerated significantly. Against this backdrop, all central areas of action of the economy and society, what we call transformation arenas, are approaching profound ecological system changes.

Digitisation is one of the prerequisites of successful ecological transformation. This is where this project "Shaping the Digital Transformation –Enabling Transformation to Sustainability" commissioned by Huawei Technologies Germany comes into play (Wuppertal Institute, 2021). The project examines the transformative potential of digitalisation within the context of four representative fields: mobility (Koska et al., 2021), circular economy (Ramesohl et al., 2022), and agriculture and food.

Digitization is effective on multiple levels. Digital technologies and applications make it possible to improve current procedures, processes, and structures (Improve). They can also help us take the first steps toward new business models and frameworks (Convert). At the same time, however, digitisation must also be used to further transform our economy and value creation mechanisms reorient society and the way we live (Transform) (Figure 2). It is this last level of impact that will be critical for the success of ecological change. This last point must therefore become the focus of debate. However, these three levels of impact are interlinked. They influence each other and so must be addressed with a holistic approach.

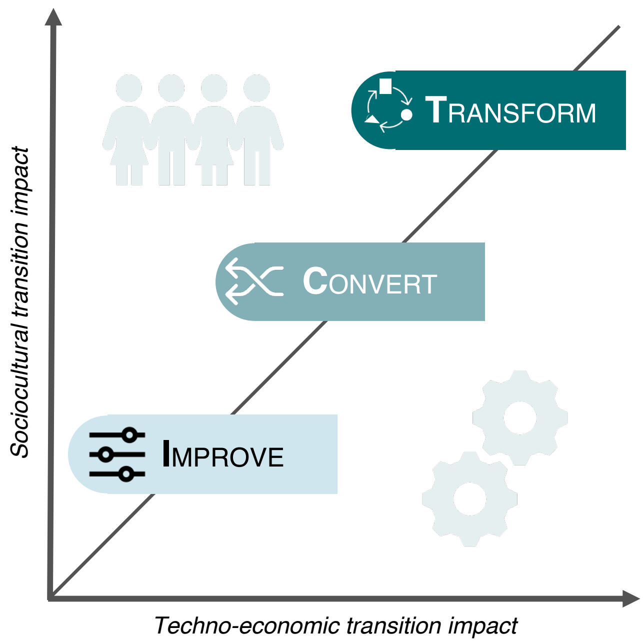

Figure 2: Impact levels of digitalization for sustainability transformation (Source: Own presentation)

All digital solutions are based on data. A sustainability transformation through digitalisation will only be achievable when we can properly obtain, link, and use data. However, data is not a homogeneous raw material. When thought leaders say, "data is the new oil of the 21st century," they miss the core of the problem. Data comes with multiple formats, structures, and types of content, and it is generated and stored in many different ways, in many different places, by many different actors. Ultimately, data only gains value when we know how it was collected is known and make it usable for a specific purpose. The challenge we then face is figuring out how to tap into and effectively utilize this rich yet fragmented cosmos of data for sustainability.

In our opinion, the discussion on what structures and prerequisites are necessary for the system-changing use of data has only just begun. This study is intended to be used as a starting point for this conversation as it will clearly outline the opportunities and prerequisites for a data-based sustainability transformation.

In our report, we will be speaking about more than just personal data, which is already at the centre of important social and political debates about data protection, personal rights, and informational self-determination. We will also focus specifically on environmental data, data from plants, machines, infrastructure, and Internet of Things (IoT) products, which are created in the physical world. Since more and more sensors are being created and connected more closely every day, it is safe to assume that more and more diverse data will be generated and recorded in the future.

Our task will be to use this data for systemic solutions in the respective transformation arenas more intensively than before. This will require different stakeholders to work together to transform infrastructure, value chains, and economic structures. Cooperative and collaborative data handling, in particular thematically structured data ecosystems ("data spaces") that increase the discoverability of relevant data and its exchange, will be basic prerequisite for the success of the necessary transformation.

In the next chapter of this paper, we will outline the special importance of system innovations for sustainability transformation. In Chapter 2, we will briefly examine boundaries needed for effective data use. Both of these perspectives underline the importance of collaborative data use. In Chapter 3 we will discuss more in depth the possibilities and prerequisites for collaborative data use. Finally, in Chapter 4, we will draw our conclusions on how best to design data ecosystems for sustainability transformation.

This report is based on the results of an interdisciplinary workshop on "Data for Sustainability Transformation - Actors, Innovations and Ecosystems" in which experts from international research institutes, civil organizations, public authorities, and private companies participated. For a full list of participants, please see the acknowledgements. This report supplements the workshop discussion with findings from other research and discussion on the technological, economic, and political development prospects and the implementation conditions for data infrastructures, data spaces, and data ecosystems.

2 The Goal: Enabling System Innovation

Within the next few years, we as a society must work within the bounds of our current global ecosystem to figure out how to create the conditions that will allow us to organize our lives and economies for long-term success (cf. Keppner et al., 2020; Rockström et al., 2009, 2021; Steffen et al., 2015). This will require fundamental changes in all aspects of life. Marginal improvements that make our current behaviour slightly "greener" will not be enough.

Such fundamental changes include transitioning to a fully renewable energy supply, achieving both industrial and consumer climate neutrality, and drastically reducing global resource consumption. In all key areas of action - from energy, resources, and water to industry, mobility, consumption, cities, agriculture, and nutrition, right through to education and health - we are facing radical, systemic changes, the likes of which we have never seen before. However, our ultimate goal is no different from the comprehensive realignment of the economy and society that was described more than a decade ago as the "Great Transformation" (WBGU, 2011).

In this paper, we will talk about transformation arenas (Figure 3) in which there are imminent changes and comprehensive system reorganization expected in terms of policy frameworks, incentive systems, market structures, infrastructures, value chains, and behaviours (Schneidewind, 2018). It is obvious that change must take place at different levels, like technologies and infrastructures, economies and markets, policies and institutions. However, a transformation must also occur within the very cultural foundations and social norms that shape and guide our actions as human beings. As individuals as well as together as societal groups and organizations, we need to build a new transformative literacy that equips all people with "the ability to adequately understand transformation processes in their multidimensionality and to bring our own actions into transformation processes" (Schneidewind, 2018).

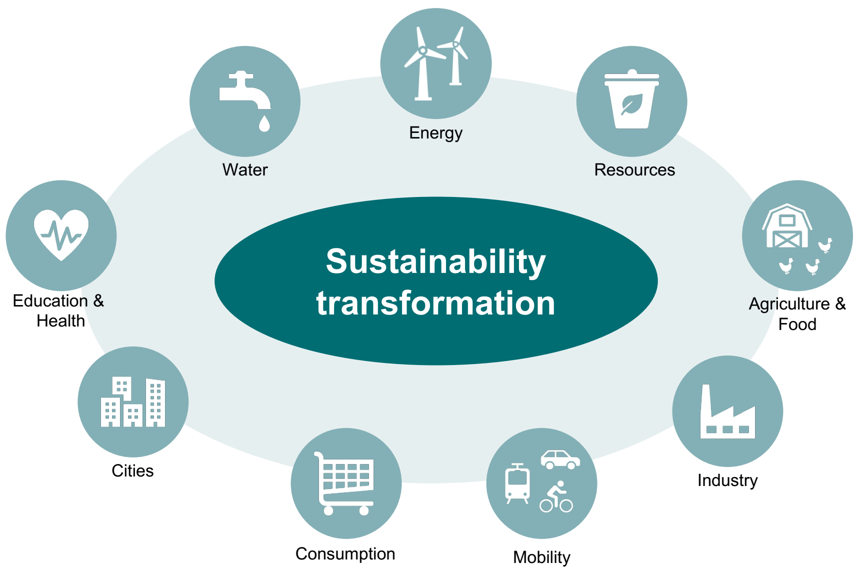

Figure 3: Arenas of Sustainability Transformation (Source: Own Presentation)

2.1 Initiating system innovation

To kick-off **system innovation**, we need new concepts, solutions, and structures that initiate and consolidate change processes at various levels. We will also need to facilitate more interaction between the different actors in all transformation arenas. As we see it, system innovation must do more than simply optimise or upgrade individual technologies or applications. It must also create new structures and possibilities for long-term action, upon which further technological developments, innovation processes, new business models, and more can develop. (Geels, 2005; Midgley & Lindhult, 2021; Mulgan & Leadbeater, 2013; Schlaile et al., 2017).

System innovation changes the structures and organizational forms of how services are provided in transformation arenas. It changes how these services are made available and how our needs are met. As new approaches to coordinating services emerge, new constellations of actors will also be formed. The actual added value of system innovation arises from the synergetic interaction of diverse technology components and the individual contributions of these actors, each of which would have little to no effect on its own. This combination of complementary actors, technologies, competencies, and services will make it possible to address even greater challenges and thus build alternatives to existing non-sustainable structures.

A classic example of this kind of innovation can be found in the smart local energy systems that are coordinated to better utilize sustainable, decentralized energy mixes with high shares of fluctuating power generated from renewables, new consumption structures, and new load profiles, such as e-mobility. Together, these systems tap into previously out-of-reach options for dynamic consumption and flexible management of consumers and electricity storage (BMWi, 2017; dena, 2021). Another example is the concept of EcoMobility in which climate-friendly public transport solutions, sharing services, and on-demand services are networked. These networks create an attractive, functionally equivalent alternative to the use of private cars by bundling these individual modules and ensuring smooth interactions between different systems during journey planning (Koska et al., 2021). System innovation will also be required for a climate-friendly and resource-efficient circular economy and for any efforts to reorient our current value chains toward circular, longevity- and material-conservation-oriented business models (Ramesohl et al., 2022).

That being said, actors' ability to act and strategize is fundamentally based on the **system knowledge** available to them. Understanding and using the past, current, and future conditions, developments, and implications of these systems is difficult given the diversity of interactions between global and regional ecosystems with the social, technological, economic, and political transformation arenas. There are often no simple solutions under these systems as the complexity of these correlations and interactions make even describing problems and mechanisms of action difficult. In addition, processes are often not linear. Abrupt or exponential changes make development dynamics difficult to predict. Path dependencies (*lock-in effects*) result in even more parameters that must be taken into account during analysis. Regular updates to controlling processes based on historical data are thus becoming increasingly difficult. So, as demand for sustainable economic and social transformation increases, so too will the demand for system knowledge and for key underlying skills. These skills will include the ability to: measure and describe systems, sub-systems, and problem situations; analyse and assess influences and development trends; model interdependencies and simulate the effects of intervention; forecast future developments; and monitor, adapt, and learn from other's designs and implementation measures.

2.2 Aligning system innovation

System innovation, as defined in the previous section, arises from the interaction of numerous individual innovations made by different actors. The key challenge for policymakers is, therefore, to trigger a self-organization of these actors so their innovative forces can be bundled and aligned towards common sustainable transformation goals. This requires creating the strategic-normative foundations to guide the search and expectations of the innovation actors (*directionality of innovation, guidance of search*, cf. also Hekkert et al., 2007).

A clear and content-related strategic directionality can help legitimize innovation efforts and results. Furthermore, such directionality can promote broad acceptance among all stakeholders and provide clear incentives in terms of scaling and commercialization.

Mission-oriented Innovation Policies (MIPs) offer an approach that specifically embeds this kind of clear policy framework into functioning innovation systems. The European Commission also supports this concept as it takes into account both innovation dynamics (*innovation rate*) and innovation direction (Mazzucato, 2018). [1]

The basic idea of an MIP thus complements the classical approaches of open-ended funding for basic research and development. It builds on the classical approaches' ability to promote technologies and competencies by achieving defined milestones in climate, environmental, and resource protection in clearly defined fields of action and by triggering transformative system innovations that contribute to socio-ecological change in the economy and society.

2.3 Embedding system innovation

To permanently unlock the full potential of system innovation, the strategic orientation and stimulating and guiding boundary conditions that affect these changing systems must also be defined. It is these market structures and regulatory frameworks that will determine what opportunities, risks, and subsequent economic successes these innovation strategies and entrepreneurial activities will produce. This also influences actors' motivation and ability to self-organize and thus has a major impact on the direction and intensity of innovation dynamics.

The first key step to setting this strategic orientation is to provide overarching economic incentives through ecologically oriented CO2, energy, and resource prices. Furthermore, previous market logics must be examined. One example of an area in desperate need of improvement is the economic incentive systems in agriculture. These are already being discussed as part of the Common European Agricultural Policy (CAP) reforms. Through these reforms, additional eco-schemes, whose ecological requirements go beyond the obligatory standards, will help open up new income for farms and to increasingly remunerate the agriculture sector for protecting the ecosystem. This will support a profound change in direction from the previous agricultural policy and the traditional market structures characterised by international competition, price pressure, and industrial production logic (Zukunftskommission Landwirtschaft, 2021). Further market-relevant parameters and scarcity signals should be addressed when setting ecological indicators such as absolute emission and consumption limits

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[1] For an in-depth presentation of the approach of "Mission-oriented Innovation Policy", see (Hekkert et al., 2020; Janssen et al., 2020; Kattel & Mazzucato, 2018; Kuhlmann & Rip, 2018; Mazzucato, 2018; Mazzucato et al., 2020; Wanzenböck et al., 2020; Wittmann et al., 2020). A similar approach is also proposed for the German High Tech Strategy 2025 (Hightech Forum (ed.), 2021)

in emissions trading, targets for recycling and reuse quotas, and prohibition of specific practices.

Successful change in transformation arenas thus depends on intertwining system rule design and system innovation. Investment in long-term structural innovation will only be attractive if clear overarching objectives, mission-oriented support, and consistent incentive systems are provided to serve a framework for actor innovation.

It is clear that system innovation requires a *multi-level perspective* that encourages implementation at different levels of the economy, society, and politics as well as the networking, communication, and interaction of many different actors (*multi-actor activities*). This is where the greatest potential of digitalisation lies. Digitalisation enables new information relationships, access and exchange of knowledge, and new forms of organisation and control of processes and structures. Simultaneously, it improves our ability to observe and analyse our environment so that we can better understand related trends, influences, and interactions. Our scope for action is becoming larger and larger, giving us new starting points for building the transformation literacy we need.

System innovation needs data - it just has to be the right data and that data has to then be used effectively. We will discuss this further in the next chapter.

3 The Challenge: Making Data Usable

Data is at the heart of every digital solution. Data makes it possible for us to observe, explain, predict and act. With the technology of today and tomorrow, we can do these things at an unprecedented level of detail and speed. Over the next few years, more and more data in our everyday lives and environments will become available, opening up new potential for data-based solutions.

End devices, applications, and infrastructure are increasingly equipped with connected sensors. Our production facilities, buildings, vehicles, smartphones, household appliances, and even our clothing generate data about how and where they are used. As a result, the IoT field continues to grow.

The digital recognition and processing of text, speech, and images using artificial intelligence is rapidly progressing and generating new data streams. These "emerging data streams" also include a growing amount of data that is freely available online. In particular, a lot of this new data is unstructured or semi-structured data from the Internet, such as search data and social media data. Similar approaches are also being used to enable machine processing and evaluation of large volumes of text and satellite image recognition for environmental protection (Boll et al., 2022; Jetzke et al., 2019).

Combined by these approaches, this data can extend the system knowledge discussed in the previous chapter to improve data utilization for system innovation and sustainable development in transformation arenas.

3.1 Data-poor fields of action

In contrast with data-rich areas such as digital platforms and social media, our physical fields of action like transport, industry, and everyday administration are still comparatively data-poor (Arnold et al., 2020). In these physical fields, data is generated and accumulated in many different places, resulting in high fragmentation and heterogeneous formats. This means that, unlike large digital platforms, the data in our physical world is not concentrated in the hands of only a few actors. In fact, it is usually distributed across many applications, devices, systems, and users.

This has direct consequences for system innovation. While innovation in data-rich environments mainly entails processing huge amounts of data, carrying out complex analyses, and recognising hidden patterns, innovation in data-poor contexts must overcome completely different challenges. The core task of innovation in data-poor contexts is to identify relevant data and data sources, merging said data, and interpreting it to make it usable. This requires the cooperation of many actors as it relates to collaborative data generation and use and how data sources can be opened up for new, common purposes.

The focus is therefore not on data per se, but on the value and usability of the data for transformation tasks. A purely quantitative increase in data volumes is not expedient. More is not necessarily better in these cases. The focus of these efforts must be put on the quality and usability of data. We need to deal with data wisely, through effective and proportionate data acquisition and use. The following two aspects also support this approach:

1. Data use itself causes environmental impacts

Although data itself is intangible, the physical realisation of data use causes negative environmental impacts. The production, operation, and disposal of sensors, data centres, communication networks, and end devices that record, store, transmit, and process data consume raw materials and energy. This is a problem that has already been recognised and is being addressed by a variety of private and political initiatives for environmentally-friendly and climate-friendly digitalisation.[2] Despite this progress, it is true that environmental impacts cannot be completely avoided. In particular, many problems remain unsolved when it comes to the use of "ecologically-questionable" resources (Gröger, 2020; Gröger et al., 2021; Köhler et al., 2018). This puts the focus on the actual consumer of physical hardware, i.e. the applications, business models, data architectures, and software solutions that determine the selection, type, and extent of end device and infrastructure use (Geiger et al., 2021; Wurm et al., 2021).

Unnecessary use of data must therefore be avoided. However, given the important role digitalisation is playing in many solutions to ecological problems, we cannot simply do away with data as a whole or use it in an overly restrictive manner. This means that in most practical cases, the collection, connection, storage, and utilization of data must be measured against the overarching purpose and benefit of the specific application. This sharpens the focus on establishing an appropriate temporal and spatial resolution of data as well as an optimized temporal and spatial organization of the collection, forwarding, and processing of data.[3]

2. Data quality trumps data volume

Data itself does not create any value. Its value to a specific use case arises from how it is embedded into a context, and then prepared and processed in a target-oriented manner (Arnold et al., 2020). This value is largely determined by the quality and, in particular, the accuracy of the data, because the efforts and costs for cleaning and preparing raw data (also known as data wrangling and data cleaning) usually account for the lion's share of the work data scientists do in big data projects. The marginal utility of data volumes in AI applications also declines as the volume increases.

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2 As evidenced by the EU Digital Strategy (European Commission, 2020b), the BMU's Environmental Digital Agenda (BMU, 2020), and the European Green Digital Coalition (EGDC, (European Commission, 2021). Cf. also https://www.umweltbundesamt.de/themen/wirtschaft-konsum/gruene-informationstechnik-green-it. Cf. on perspectives on energy consumption and emissions from AI models (Patterson, 2022).

3 Independent of such targeted data use, it is of course, in principle, possible to derive completely new, unexpected insights from large amounts of data. This opens up a new perspective for scientific work, which is also discussed in *Fourth Paradigm or Data-Intensive Scientific Discovery* (Hey et al., 2009).

3.2 Eco-efficient and collaborative data use

In summary, data collection and use can be guided by the principle of eco-efficiency (see Figure 4). The environmental impacts of data use must be resolutely reduced. At the same time, our responsibility to maximise the ecological value of data and its contributions to transformation cannot be avoided.

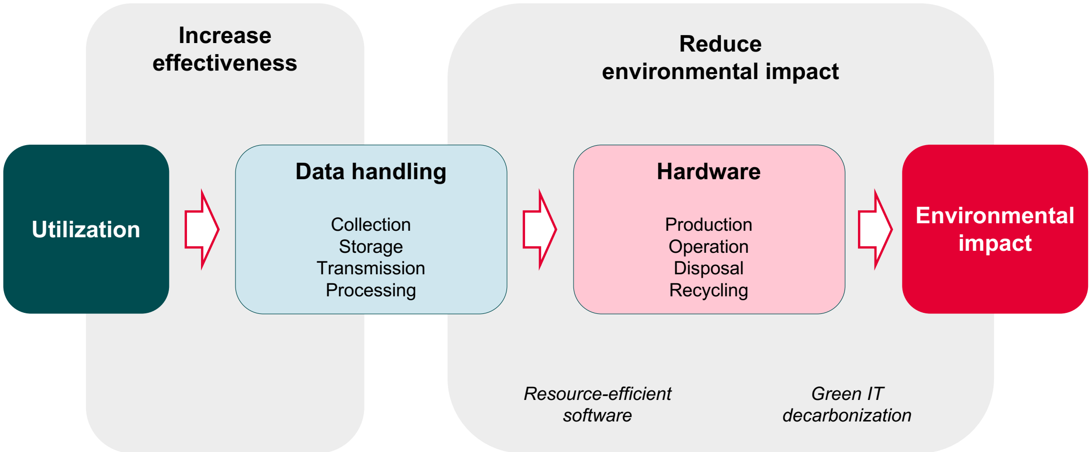

Figure 4: Eco-efficient data use (source: own presentation)

A central question to these conflicting tasks is therefore: How do we increase the effectiveness of data for system innovation, especially given the need for interaction and collaboration on system innovation design between different actors? To answer this question, we must first answer the following:

- How can the possibilities of collaborative data use in digital solutions be opened up for the system innovations outlined above?
- Which principles and structures for data organization and handling are most environmentally compatible and which will make data most effective for sustainability?
- How can data sources be opened up for new purposes, and how can different data sources be brought together?
- What roles do standardisation, interoperability, and portability play in this context?

These will be discussed in the following Chapter 4.

4 The Approach: Collaborative Data Use

The previous chapters have explained the opportunities collaborative use of data creates for sustainability transformations. Accessing, sharing, and using data from other actors is an important prerequisite of collaborative use and helps keep the environmental impacts associated with data within tolerable limits.

The search for socially optimal data access governance is still ongoing, however the best solution will most likely be context dependant. Market-based data trading is already proving to be an effective answer to this problem. This system has potential data buyers make classic "make or buy" decisions based on economic rationale (Arnold et al., 2020). For data providers, data trading opens up new monetisation possibilities that could benefit other actors for any data that is generated as a product or by-product. This data can either be traded directly or offered as data-based services (Martens, 2018). This system can also be used to extend current business models. Under these systems, in addition to clearly definable data provider-buyer relationships, barter transactions, or mutual data exchange, will also take place.

Mutual data exchange in particular potentially offers novel ways for actors to interact and for existing interactions to expand. Particularly relevant for industrial transformation is **data sharing along a single value chain**, in which data gathered at one stage of the value chain can be used at another stage. For example, data about the exact material composition of plastic packaging, which is usually held by the manufacturer, can be used by recyclers to optimise the reclamation process and thus improve the effectiveness of recycling activities. Similarly, data sharing can also open up new options for action in other transformation arenas.

Furthermore, open data from public and private sectors can trigger system innovation. A concrete example of this is the improvements to sustainable mobility services that can be achieved by connecting information and booking systems for mixed-mode commuting (Koska et al., 2021).

This is where political design is needed to connect actors beyond already established commercial data exchange relationships and to mobilise them for digital and sustainable system innovation. In this chapter, we will outline conditions, approaches and tools that can enable data sharing while ensuring solutions remain flexible and scalable.

4.1 The value of context

As was explained in the previous chapter, data does not have its own intrinsic economically-usable value. It only develops its own value when it is used in a specific context (Arnold et al., 2020; Martens, 2018). This includes, for example, when it is used to make better or at least better-informed decisions (cf. (Cao, 2017). The Smart Circular Economy Framework (Kristoffersen et al., 2020) strongly links this process to an increase in system resource efficiency (see Figure 5).

The implication is that data access, rather than data itself, is most import. However, access it is not the only decisive factor in whether data can yield benefits. The ability to discover, understand, and make use of data that is specifically suitable for one's own context is the crucial determinant. This ability becomes increasingly crucial the further the context of data use is from the original context of data collection. Thus, the ease with which data can be found, interpreted, and integrated becomes particularly important for the collaboration within system innovation (e.g. along a value chain) required for sustainability transformations.

The following sections outline these prerequisites for collaborative data use at different design levels. These include interoperable systems and components (section 4.2), interoperable data spaces (4.3) and interoperable data ecosystems (4.4).

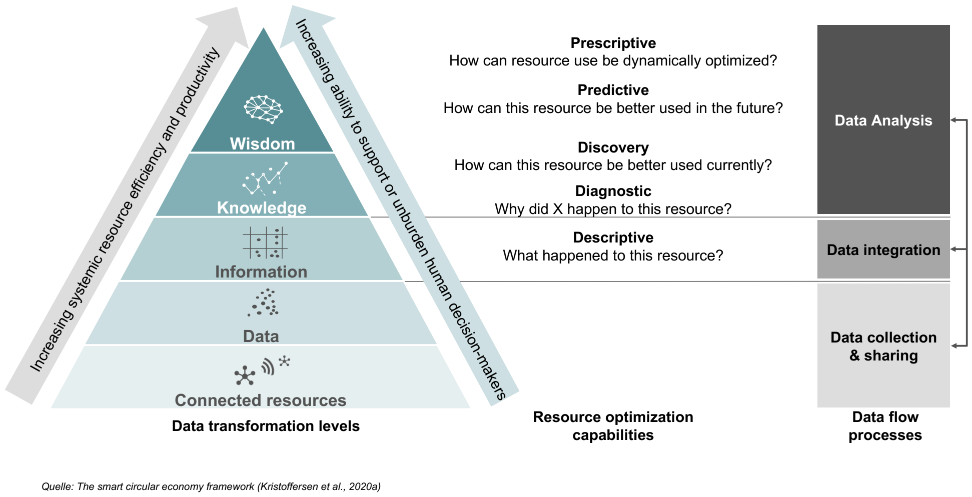

Figure 5: Smart circular economy framework. Source: Own presentation in (Ramesohl et al., 2022) after (Kristoffersen et al., 2020)

4.2 Interoperable systems and components

The first step to determining the usability of data is gain awareness of its existence and its suitability for the intended use. Within established business relationships between individual actors, direct exchanges of data may be suitable for this purpose. However, if your aim is to tap into multiple potential data sources that no single actor completely controls, as in the case in most sustainability transformations, then the **findability** of data becomes a challenge. This challenge is currently addressed by some data and API marketplaces through "data discovery" offerings (Meisel & Spiekermann, 2019). These offerings use mechanisms such as searchable catalogues, queries on specific data needs, notifications of new offerings and trends, and other data products that specify desired characteristics in terms of content and quality.

In order for data to be used by other actors, these differing systems must then to communicate with each other. Depending on the situation, data portability or interoperability are the key requirements here. **Data portability** relates one's own data being transferred from one service to another.[4] Portability therefore deals with changing which legal or natural person acts as the data provider. An example of this mechanism is the example provided in the EU Data Act for Cloud Services proposal (Cloud Switching, cf. (European Commission, 2022b).

However, the ability to exchange data and information between different systems, applications or components is also crucial for the digital-ecological transformation of the economy and society. This system property is subsumed under the term **interoperability** (cf. Gasser & Palfrey, 2007). Although is sometimes treated as a synonym of compatibility, the strict definition

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4 The right to portability of personal data is also enshrined in the EU by the General Data Protection Regulation, e.g. when switching social media providers. However, as mentioned, this aspect is not further elaborated in this report.

of interoperability goes well beyond this (Figure 6). Two systems or components are compatible if they can exchange data with each other. Systems and components are only considered interoperable if all participants in their network are compatible with each other without relying on a central actor to serve as an exchange or pivot point (Kerber & Schweitzer, 2017; Weiß, 2018).Figure 6:3

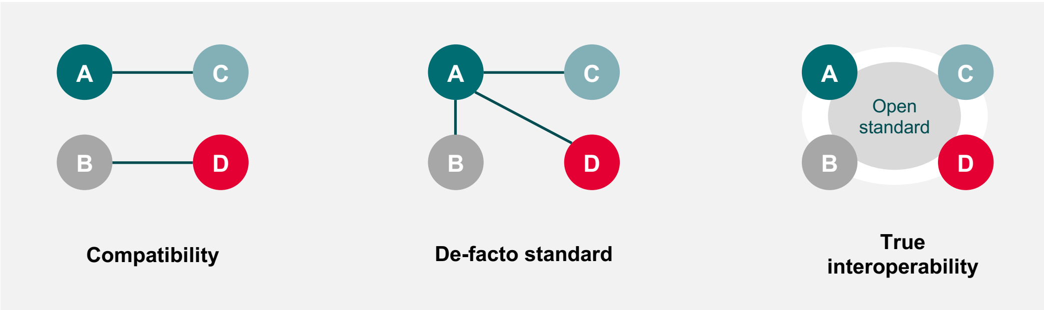

Figure 6:3 Characteristics and delineation of interoperability (Source: Weiß, 2018)

Interoperability is key for digital collaboration between multiple actors, which in turn is key for sustainable industrial transformation. Interoperability must also be ensured at multiple levels (Kubicek et al., 2019). At the syntactic level, common data exchange formats and the characters used therein must be defined. The semantic level, on the other hand, describes the content and order of the content of a data set. Semantic interoperability thus refers to the ability to understand the meaning of exchanged data. Finally, organisational interoperability requires the alignment of workflows where data is generated and used. All three levels of interoperability are crucial for the success of digital-ecological transformation.

Standards can be particularly helpful in enabling interoperability and the correct exchange of data (Kubicek et al., 2019). Standards design must often balance the need for a sufficiently universal structure to meet interoperability requirements with the need for agility so that the structure can be applicable to different actors, situations, and frameworks. This tension can only be resolved if the stakeholders involved in the most common use cases are involved in the standardisation process. Defining key use cases for sustainability transformation is therefore a critical first step before the standardisation process can begin.

While requirements for standardisation such as accuracy, flexibility, openness, and sustainability are relatively easy to define, no universally applicable specifications can be set for the selection of use cases or for the method for standardisation itself. Possible solutions for this search process range from market-based competition between different standards to collective processes moderated by standardisation organisations to politically prescribed interoperability requirements.

A complementary approach to interoperability standards is the use of **adapters and converters** that can be used to convert data from one format to another. All approaches have their own advantages and disadvantages that must be weighed against each other in their respective context (cf. Kerber & Schweitzer, 2017).

One instrument that is important for achieving semantic interoperability in the context of industry transformation is **ontology**. Ontology describes permissible terms (concepts) and relationships between them in a subject area (domain), and can be captured in a machine-readable way using the Resource Description Framework (RDF) or the Ontology Web Language (OWL) (Baqa et al., 2019). One data structure that can be used to map the instances of the concepts described in ontology are **knowledge graphs** (Kejriwal, 2019). While knowledge graphs are already being used in Industry 4.0 to describe standards, requirements, and frameworks (Bader et al., 2020), it is still unclear whether they will be useful for system interoperability.

As shown above, we must do more with data then just exchange and merge it. Information and applicable knowledge must also be derived from data in order for that data have an impact. For this step, data must be transferred from the original context it was generated in to the new context it will be used in. This requirement cannot be met with standards alone. It also requires the exchange of **metadata**, i.e. data about data. Metadata contains information about the context of data generation, as well as the content and the quality of data. Metadata must also be interoperable for the data itself to be correctly exchanged (Kubicek et al., 2019).

The requirements for data sharing discussed here can be succinctly summarised using the FAIR principles originally established for research data management (Wilkinson et al., 2016):

> *In order to create maximum benefit, data should be finable (findability), accessible (accessibility), interoperable (interoperability) and reusable (reusability).*

4.3 Interoperable data spaces

System innovation requires different actors want to cooperate closely using data. This cooperation though requires more than just system interoperability. In addition to data exchange, harmonising processes, interfaces, and data structures also plays a decisive role. This harmonization can be is made possible through structures known as **data spaces** and **data infrastructure** information technologies (Otto & Burmann, 2021).

Reference architectures can be used to formalize data infrastructure descriptions and to bring together the different perspectives and requirements of the actors involved. These architectures help create agreed upon structures for this cooperation which define what information will exchanged. They also form the basis for the development and integration of data technology systems (Arnold & Liebe, 2018).

One international initiative for collaborative data space is the **International Data Space** (**IDS**) (Otto et al., 2019; Otto & Burmann, 2021). The focus of the IDS initiative is to increase interoperability, and to share and collaborate on data. The core of IDS is the **IDS-RAM** reference architecture model. This model specifies a distributed software architecture for sharing and exchanging data that distinguishes between data givers and data receivers. The bilateral, decentralised data exchanges it creates are mediated by so-called broker services that deliver both effective data and effective metadata. Standardised data services, for example, those that convert data into different formats, are made available via an app store. Semantic interoperability is achieved with an information model that includes a jointly maintained vocabulary for describing data as well as data-generating and data-using services. Data source connections are established via the **IDS Connector**. In addition to delivering metadata, this connector also manages and enforces machine-readable terms of use, effectively permitting or prohibiting use as per the exchange agreement (Otto & Burmann, 2021).

Another reference architecture developed specifically for value-added networks is the Reference Architecture Model Industry 4.0 (**RAMI 4.0**). The purpose of this model is to "develop a cross-industry understanding of which standards, norms, etc. are necessary for Industry 4.0" (Arnold & Liebe, 2018, p. 15). RAMI 4.0 consists of three dimensions: (1) layers, (2) life cycle and value chain, and (3) hierarchy levels (see Figure 7, German only). These layers, including the business, functional, information, communication, integration, and object layers, represent different perspectives from which objects (assets) in an IT system are represented. The stages in the life cycle and value chain of a product are mapped in RAMI 4.0 by product type and instance (i.e. the product's concrete, material characteristics). The hierarchy levels ultimately extend from the individual product to the connected world.Figure 7:Figure 7:

The link between the real world and its virtual representation in IT systems takes place in RAMI 4.0 in the integration layer and is established via the **management shell**. With a management shell, every real object in Industry 4.0 receives a digital twin, through which the object is described in IT terms and addressed digitally. This allows it to be integrated into the overall context.

While RAMI 4.0 as a reference architecture is necessarily at a high level of abstraction, there are already approaches to make it more concrete, often within individual layers. For example, the **Open Platform Communications Unified Architecture** (**OPC UA**) is a prime example of how interoperability systems can be advanced as it defines communication interfaces for the cross-company exchange of machine data (Arnold & Liebe, 2018).[5]

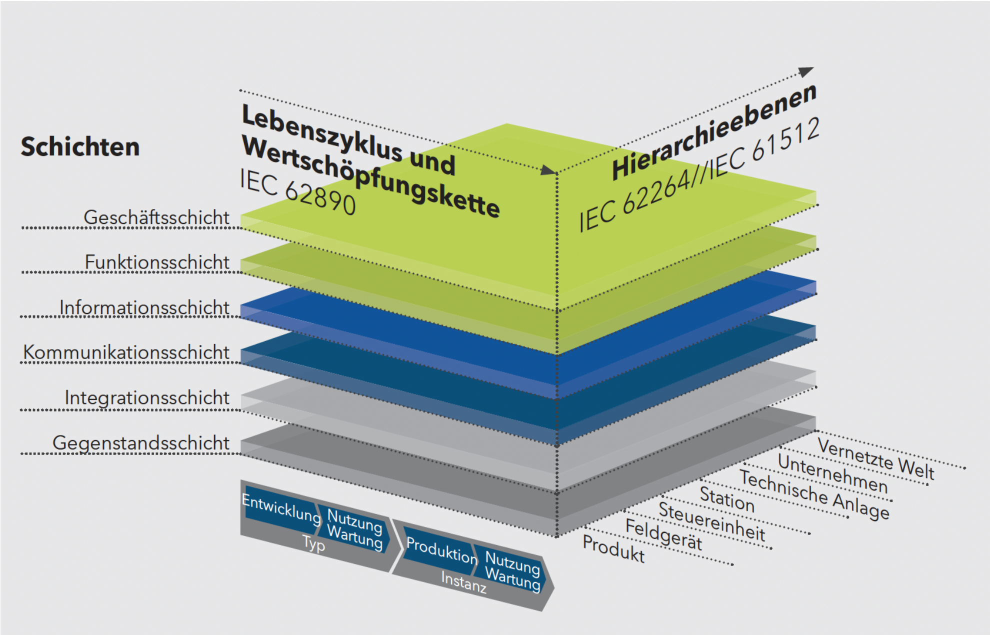

Figure 7: Reference Architecture Model Industry 4.0 (RAMI 4.0). Source: (Arnold & Liebe, 2018) based on (Platform Industrie 4.0, 2016), German terminology from (DIN Deutsches Institut für Standardization e.g. V., 2016).

4.4 Interoperable data ecosystems

The data spaces and reference architectures discussed in the previous section are available for and applicable to a variety of use cases. As a result, they are highly scalable and can be used as a basic framework in different industries. However, such data spaces and architectures are still too generic for the development of functionalities that can be applied in specific use cases.

This development occurs in thematic data ecosystems, in which different actors cooperate to achieve a common goal. Such goals can range from data exchanges to the development of new business models (Lis et al., 2019). Actors within a data ecosystem have a variety of roles, which can include the data provider and the data consumer, mediating roles like data brokers, and service or infrastructure providers.

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5 For current information about the OPC UA standard, see https://www.vdma.org/opcua.

A key feature of many data ecosystems is that they are decentralized, meaning the storage and processing of data take place separately. By storing data at the source, control over the data remains with the data holders (cf. Gaia-X, o. J.-a; Lingelbach, 2020). **Federated data ecosystems** can also be discussed in this context, where data is not available through a common database schema, and semantic interoperability is achieved through integration. (cf. Otto & Burmann, 2021, p. 284) Common standards and **rules** for the storage and processing of data are also key features of any data ecosystem (cf. Gaia-X, o. J.-a).

A notable example of a data ecosystem is **Gaia-X**. This project, which is supported by more than 300 member organisations from across the business, politics and research domains, has set "the goal of creating a secure and networked data infrastructure in Germany and Europe". Gaia-X also promotes competition within the data economy and has a particular focus on edge and cloud services (cf. BMWi, 2019, p. 11 f.). In addition to the typical characteristics of data ecosystems mentioned above, such as data sovereignty, decentralization, and interoperability, Gaia-X is committed to the **values** of openness, transparency, and security (cf. Gaia-X, o. J.-b, p. 1). The International Data Space (IDS) initiative mentioned in the previous section is also closely linked to Gaia-X.

Gaia-X and IDS both aim to increase technical- and software-related **data sovereignty**, such as the *"Ability of a legal or natural person to have self-determination over its data assets"* (Otto & Burmann, 2021, p. 284). While IDS focuses on the sharing and joint usage of data, Gaia-X goes one step further to also prioritize the storage of data, particularly in terms of cloud infrastructure. The two initiatives are concretely linked through the integration of IDS-RAM into the Gaia-X architecture (cf. ibid., p. 287).

4.5 Collaborative data use

It is becoming clear that the effective use and sharing of data requires the creation of certain conditions at different levels. Figure 8 summarizes the key design elements of collaborative data use that were addressed in the previous sections.

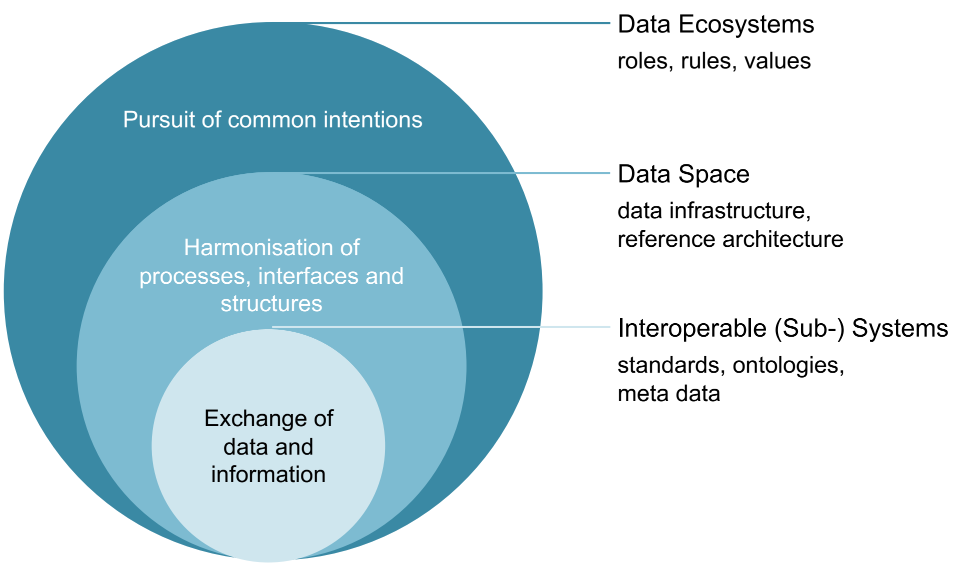

Figure 8: Design levels of collaborative data use: Intentions and design methods (Source: own illustration)

Various tools are employed to achieve the objectives of each level, which intersect with each other. Interoperability is a key prerequisite for collaboration, as it allows data and information to be exchanged between systems and components. Effective Interoperability can be achieved through standards, ontologies, and the exchange of metadata. Based on this, and with the support of data infrastructures and reference architectures, data rooms can be built in order to harmonize processes, interfaces, and structures. Common goals can be pursued only if the involved actors fulfil their roles, understand rules and values, and cooperate within a data ecosystem. Different design levels should not be considered strictly separate from one another. This has been seen with the application-specific rules agreed within data ecosystems, which have impacted the design of interoperability between participating (sub-) systems.

5 The Task: Realizing Sustainable Transformation

The aforementioned considerations make it clear that data can create value for urgently-needed system innovations if the data is findable, accessible, interoperable, and reusable (multiple times) for different actors, according to the FAIR criteria (European Commission, 2020a; Wilkinson et al., 2016). This section outlines different technical concepts and solutions, some of which are already in operation while others are still undergoing development or testing. In recent years, significant progress has been made regarding the compatibility of the design of applications and systems, the guidelines for data collection, the promotion of open data, and the creation of standards, interfaces, and the building blocks of data spaces.

All of this can serve as a solid foundation.

5.1 Open questions and data spaces

Despite much progress being made in terms of the conception and development of data spaces and data infrastructures, a number of implementation issues remain unresolved (Otto & Burmann, 2021). Some such issues concern ethical and legal aspects, while technical and economic issues also exist, all of which will require clarification in the coming years. (Figure 9).

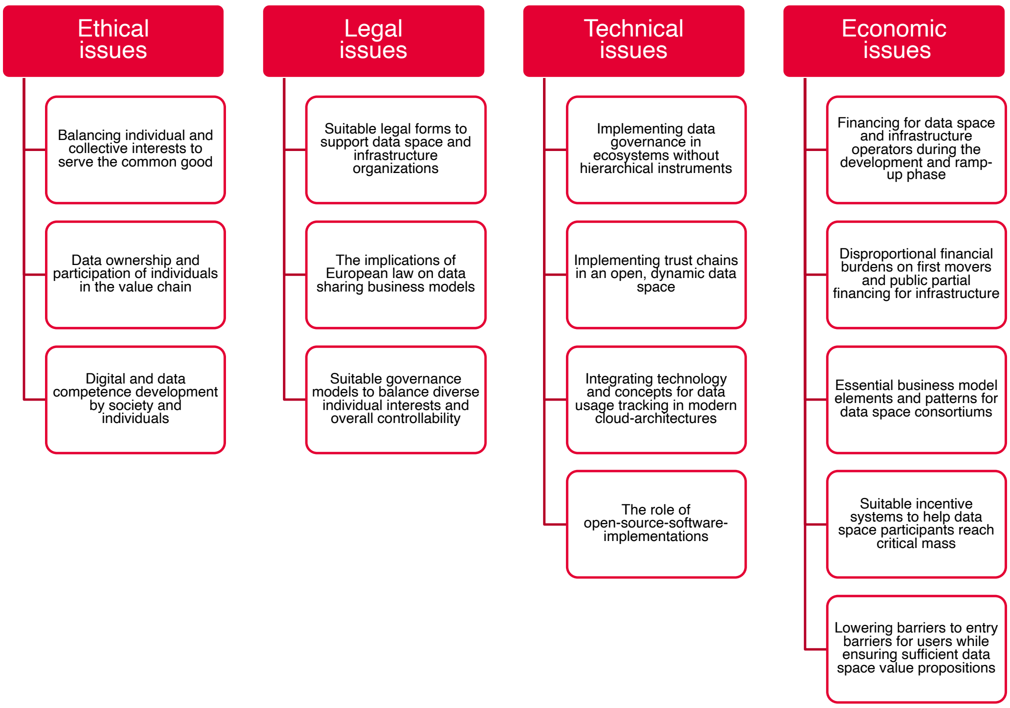

Figure 9: Examples of open questions for the design of data rooms and data infrastructures. Source: own illustration, according to (Otto & Burmann, 2021)

Many of the unsolved issues are related to practical design and concrete implementation. Therefore, the corresponding solutions should be developed step by step and based on real projects and experiences. Ideally, the development of technical functionalities and building blocks should run parallel with their application in specific use cases. New technical solutions will reveal new possibilities and application fields, while the requirements and experiences related to actual implementation will point to additional required technologies and possible solutions.

5.2 Key players

Data spaces must be broadly based, scalable, and capable of integrating new use cases in order to stimulate the dynamics of transformation. The horizontal structures necessary to achieve this must not be developed as proprietary individual solutions by either individual companies or market players. Technology openness, flexibility and individuality during application, and broad trust and acceptance of governance and rules are all prerequisites for success.

Additionally, high levels of investment and excellent technological know-how must be mobilized to develop powerful solutions. Research and development, the establishment of physical infrastructures, and the creation of organizational and governance structures are all inevitably associated with efforts, costs, and risks (cf. the "Economic issues" block in Fig. 9). A classic dilemma (the chicken or the egg) arises during such work, particularly during the development and establishment stages.

Investment into the development and expansion of new structures must be financed by the broadest possible use of such structures by diverse users and use cases. However, the attractiveness of these structures is dependent on a high number of participants. Therefore, demand is lacking at the beginning and potential users remain inactive until powerful functionalities are available, leaving us with a chicken or the egg dilemma.

Breaking this deadlock will require the broad and effectively coordinated collaboration of stakeholders from across the domains of science, industry, and politics:

- Economically and/or technologically important key players should take a leading role in initiating and steering development.
- Broad participation of other stakeholders, potential suppliers, users, know-how carriers, and so on will widen the knowledge base, strengthen compatibility and interoperability, open up additional application areas, and enhance acceptance of roll-out and scaling.
- Political support provided through research funds, funding programs, subsidies, or grants can help reduce start-up costs, lessen risks, and lower set-up costs for first-time players. This allows critical mass to be reached quickly, allowing companies to avoid parallel developments and duplicated costs.

Recent examples such as Catena-X[6] , the development of the Industry 4.0 Reference Architecture Model (RAMI 4.0), and even AUTOSAR (AUTomotive Open System ARchitecture) (Arnold & Liebe, 2018) as a framework for software development in cars, show the value of such collaborative approaches.

Irrespective of measures taken in the initial phases, the further scaling and stabilization of data spaces will depend on the healthy and long-term self-motivation of the players involved. These players will be guided by both their individual and shared expectations of future framework conditions. This affects both the opportunities that data-based collaborative solutions have to address issues in areas like new energy efficiency potential, customer needs, value creation, and business models, and effective mitigation of risks caused by overriding market trends or regulatory requirements.

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6 Catena-X was created for companies in the automotive value chain and pursues a vision of creating the "most user-friendly environment for building, operating, and collaboratively using end-to-end data chains, throughout the entire automotive value chain" (https://catena-x.net/de/).

Policy will be key to incentivizing the development of system innovations. The EU regulation on the sharing of traffic information and travel data (cf. e.g. (European Commission, 2017) has established a standard for providing cross-provider offers and services related to public transport. At the same time, it is evident that consistent progress must be made in order to promote the offers of the environmental alliance, increase the quality of these offers, and thus achieve attractive, climate-friendly alternatives to private cars. A comprehensive turnaround in transportation is achievable only if digital mobility solutions are embedded within an accompanying policy mix that promotes the expansion of the environmental alliance, changes to the regulatory framework for car traffic, financial incentives enabled through taxes and fees, and improved spatial, urban, and transportation planning (Koska et al., 2021).

The current momentum surrounding the topic of recording digital product information throughout the entire life cycle of products and materials stems from key political ambitions. These are to realize a resource-efficient circular economy and increase transparency regarding the environmental footprints of value chains (Ramesohl et al., 2022) .[7]

As mentioned in chapter 2, the political framework for future infrastructures, markets, industries, and value chains is crucial to the long-term strategic actions of players involved in transformation arenas. Clear targets for climate protection and decarbonisation, as well as for innovation policy, create guardrails for collective action and investment.22

5.3 New stakeholder groups and data institutions

System innovations are characterized by different actors cooperating along and across traditional value chains and relationships. In addition, social acceptance and social innovations play a key role in many sustainability solutions, which is why it's sensible to involve additional actors, such as those from civil society, and systematically consider the perspectives of users through participation and co-creation. This will result in the emergence of new actors and a growing need to bring together new types of data, content, and linkages. The core challenge in this regard is to adequately represent the new actors within data ecosystems and reduce barriers to participation for smaller, weaker, or private participants. This is where low-threshold offerings and user-friendly interfaces tailored to specific groups, such as civil society or public institutions, can help involve actors that possess less expertise and experience.

The willingness to share even private data increases if the right goals are being pursued and misuse is being prevented (Hardinges & Keller, 2021; Peppin, 2020). New data institutions[8], such as data trustees and data cooperatives, are increasingly being discussed within this context (Blankertz, 2020; Blankertz & Specht, 2021; Federal Government, 2021; Coyle, 2020; European Commission, 2020).

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7 One example is ongoing initiatives to specify a battery passport for electro mobility in anticipation of the upcoming EU Battery Regulation, e.g. as a Design-Sprint to the Digital Product Passport for electro mobility (https://www.bmuv.de/digitalagenda/produktpass/pkw-batterie) or within the framework of the Global Battery Alliance (www.globalbattery.org)

8 "Data institutions are organizations that steward data on behalf of others, often towards public, educational or charitable aims."(Hardinges & Keller, 2021)

Such institutions can more effectively represent the interests of data owners according to their individual preferences[9]. Experiments and pilot projects should also test the suitability of new concepts in regards to sustainable system innovations and transformational contributions.

5.4 Data access

Access to necessary data is a prerequisite for all data ecosystems. The approaches outlined above are designed to enable different actors to collaborate based on the voluntary provisioning of data in order to achieve common goals and increase benefits for all stakeholders.

In addition to the aforementioned options, which are based on reciprocity and voluntariness, there are other starting points for enabling or expanding access to data through regulatory frameworks. The key aspects of these are as follows:

- The use of machine-generated data from networked devices in the Internet of Things, such as that generated by cars. Much of this data is initially generated through the use of products, is rarely personal, and can both provide valuable information on the performance, maintenance, and servicing of products and enable new services and business models. Therefore, expanding access to this machine-generated data would open up new opportunities for sustainable system innovations. Currently, such product and machine data is typically recorded within the closed systems of manufacturers, meaning it is not accessible to the users, other actors, service providers, and so on. This is where the European Data Act comes in, for which the European Commission presented a proposal at the end of February 2022 (European Commission, 2022b). Among other things, the Data Act defines new access rights for the users of digital applications and products. In the future, they should be permitted free access to data they have generated themselves and be able to share this data with third parties such as car repair shops. Ultimately, the expectation is to uncover new innovation potential and market opportunities, especially for small and medium-sized enterprises and new market players.[10]
- Open data offerings from public institutions. Geodata and environmental data are crucial to the creation of sustainable solutions, and data strategies at both the European and national levels intend to expand access to such data and apply it in specific data spaces (Green Deal Data Space and Data Space Environment) (Federal Government, 2021; European Commission, 2022a). In Germany, the "Umwelt.info" website is currently under development. This website will serve as a central portal for environmental and nature conservation information, and as a hub for monitoring national biodiversity.[11]
- Access by public institutions to data of public interest belonging to private actors. (*private data of public interest*). Overriding societal goals or interests that support the common good may justify access to such data, while the interests of private actors in terms of privacy, property rights, copy rights, trade secrets, and so on must also be considered.

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9 This also includes personal information management systems (PIMS) (Federal Government, 2021). The specific aspects of private and personal data are not further elaborated in this study.

10 The Data Act proposal also covers data exchange rules for contracts between companies, data standards, and easier data portability when switching cloud providers. However, it was not possible to conduct detailed evaluations of draft or divergent assessments by different stakeholders within the timeframe of this study.

11 Cf. https://www.umweltbundesamt.de/umwelt-info and https://www.monitoringzentrum.de/

In the context of open data strategies, the discussion surrounding conflicting data access rights is gaining interest, especially in view of the dominant position of large digital corporations and their data-based market power. Data access rights are already addressed within various European legal acts. The Digital Markets Act mentions the creation of fair competitive conditions through access to the data of market-dominant gatekeepers, and the draft Data Act touches upon government access to private data in exceptional circumstances, such as emergencies. Another key consideration is the use of data for research purposes, as set out in the Digital Service Act or regulated by sector-specific research clauses (Specht-Riemenschneider, 2021). In each of these cases, a number of questions need to be clarified, the possibilities, limits, and rules of data access need to be specified, and the complex mesh of conflicting interests and property rights needs to be balanced. Given the importance of data-based solutions to sustainability and the common good, the discussion surrounding access to private data that is of public interest must be both intensive and emphatic. This will support the prompt achievement of practicable solutions.[12]

The outlined approaches make it clear that, particularly at the European level, the debate on data access has begun and new framework conditions can be expected in the foreseeable future. Overall, these developments should increase the availability and usability of a wide variety of data, benefitting sustainable system innovations.

5.5 Data Ecosystems and Sustainable Transformation

In the coming years, there will be an opportunity to integrate the development of data spaces and the political promotion of pilot projects within the overarching agenda of sustainable transformation of the economy and society. Many system innovations will require the seamless support of data spaces. This synergy will create the infrastructural and organizational basis for data sharing operations, which will align with common transformation goals.

Data ecosystems are crucial to sustainable transformation

In line with the German government's data strategy, we understand data ecosystems as interplay between "*... various stakeholders, services and applications (software) that use and share data for economic or social purposes. [....] In this sense, the data ecosystem is a data-based system with an innovative, technical, organisational and regulatory structure*." (Federal Government, 2021)

However, achieving this - as explained in Chapter 2 – requires stronger focus on the ecological challenges that are already apparent and ensuring they are overcome to achieve the goals of data-based system innovations.2

Many of the current GAIA-X pilot projects primarily concentrate on technological or economic goals and will only have an indirect effect on climate, resource, and environmental protection. There are still too few projects that explicitly address sustainability goals or involve sustainability actors, representing an area of huge untapped potential (Figure 10). The conception and design of sectorial data spaces, as announced in the EU Data Strategy and the German government's data strategy, are still too general. Therefore, they must be further defined through

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12 However, new data access claims are not the only obstacle. Additionally, effective data access infrastructures and mechanisms, such as research data centres or data trustees, need to be developed. (Specht-Riemenschneider, 2021) defines the combination of data access infrastructures and data access claims as a data access ecosystem.

concrete, sustainability-oriented use cases (Federal Government, 2021; European Commission, 2020a, 2022a).

Environmental policies and sustainability communities should become more closely intertwined with ongoing processes in the context of IDS, Gaia-X, and so on. In addition, they should allow the development of infrastructures and institutions so that the upcoming transformation tasks can take effect.

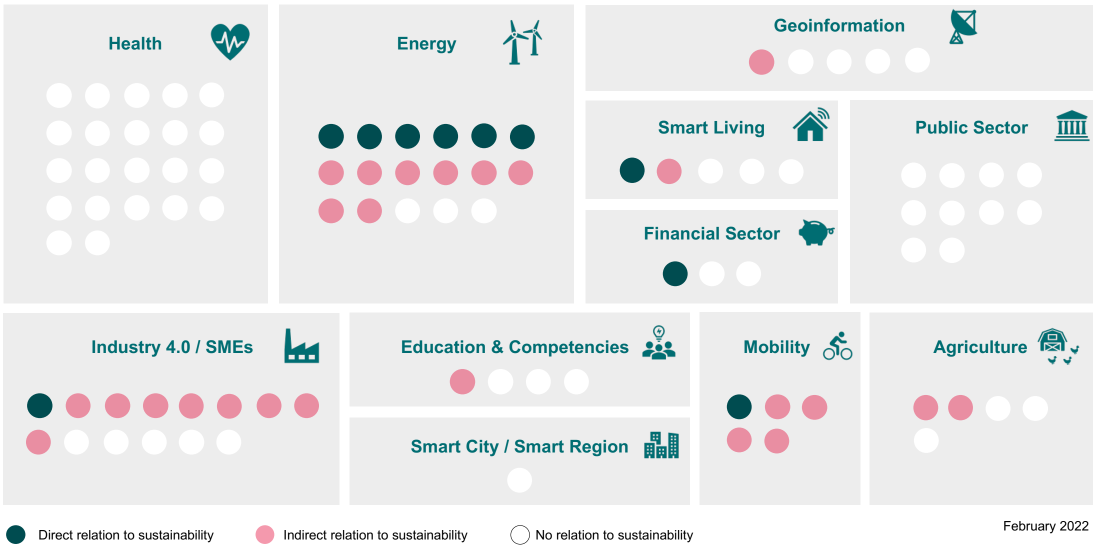

Figure 10: Illustration of the sustainability references of GAIA-X projects (Source: own illustration)

6 Conclusion

The topic of data has taken centre stage in social and political debates. At both the European and national level, there is intense discussion surrounding the significance of data, the possibilities for obtaining and using data, and the policies for handling and exploiting data. The focus remains fixed on personal data, often in the context of communication and information services, such as social media.

However, there is still much to do to realize an ecologically sustainable transformation of both the economy and society. With digitization and data-based solutions offering new opportunities for improved climate and resource protection, it is essential that we further discuss data produced by products, plants, devices, infrastructures, and the environment. The key players in sustainable transformation must open themselves up to these opportunities and actively help shape the emerging action fields.

Within this report, we have highlighted the importance of realizing closer cooperation and the collaborative use of data, which will require the establishment of technical, organizational, and institutional conditions. Data ecosystems are necessary for sustainable transformation, and an integrated approach covering numerous factors is needed to realize such systems (Figure 11):

- The players involved, particularly companies, organizations and public institutions, must acquire the ability to collect and process data and, above all, derive insights into related value creation. Data is only valuable if it strengthens an actor's ability to take action, which is where action-oriented and ***transformative data literacy*** becomes important. Many industry players, including small and medium-sized enterprises and public institutions, are still in the early stages of this process.
- Sustainable system change hinges on system innovations, while system innovations require data **ecosystems to provide collaborative data use**. Reliable and trustworthy technical infrastructures, data architectures, and rules for data access and use make it easier for various actors to jointly develop digital system innovations, without relinquishing sovereignty over their own data.
- Collective action is built upon common goals and a willingness to commit to them, especially financially. Politics and society should create the guard rails for such action through a **mission-oriented transformation policy** that aligns system rules with sustainability and, above all, creates economic incentives for investment into transformative, data-based system innovations.
- Our shared understanding of the state of the world and expected developments, as well as our systems knowledge, must constantly evolve. **Open data strategies** primarily provide access to public data about areas that are highly relevant to the welfare of society, such as the state of the environment, and it is essential to expand upon these strategies. At the same time, we must improve our understanding of what data belonging to private actors is of public interest and under what conditions said data can be made accessible for the common good. We are still in the early stages of establishing open data strategies and a culture of extensive data sharing on a broad basis.

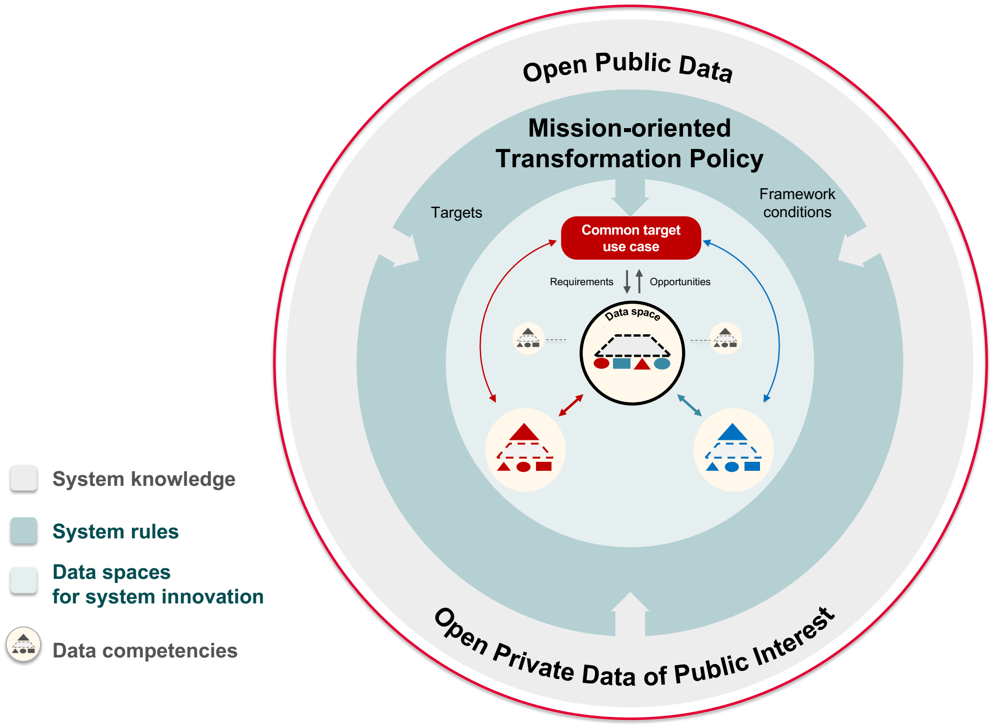

Figure 11: Data ecosystems for sustainable transformation (Source: own illustration)

The considerations above clearly show that the technical foundations for building and using data ecosystems are already available or being built. The key task is to bring together the approaches outlined above and, bearing in mind the importance of taking decisive action, intensively improve them. A window of opportunity will present itself in the near future, which must be seized to implement a mission-oriented transformation policy:

- Support for data spaces in the form of basic research and economic policy support is creating new opportunities for taking action. Now more than ever, pilot projects must be measured against ecological criteria, and sustainable use cases must be established and their contributions to sustainable transformation taken into account.
- Environmental and sustainability policy must focus more heavily on the transformation potential of data-based system innovations and strengthen the prospects of success and demands of ecological use cases. This should be achieved through targeted incentives and guard rails for the socio-ecological transformation of both the economy and society.

Ultimately, it is clear that digitization and sustainability must be considered as one in the sense of a true "*Twin Transition*". The time is more than ripe for an integrated approach that creates an overarching cross-departmental framework for the realization of a successful, digital-ecological transformation.

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